

PIONEER ENGINEERING

AND MANUFACTURING COMPANY

(NASA-CR-175772) MANUFACTURING COST
ANALYSIS OF A PARABOLIC DISH CONCENTRATOR
(GENERAL ELECTRIC DESIGN) FOR SOLAR THERMAL
ELECTRIC POWER SYSTEMS IN SELECTED
PRODUCTION VOLUMES (Pioneer Engineering and G3/44

N85-27380

Unclas
21237

DIVISIONS:

- WETTLAUFER
- INDUSTRIAL
- RESEARCH AND DEVELOPMENT



FINAL REPORT

**MANUFACTURING COST ANALYSIS OF A PARABOLIC DISH CONCENTRATOR
(GENERAL ELECTRIC DESIGN)
FOR SOLAR THERMAL ELECTRIC POWER SYSTEMS
IN SELECTED PRODUCTION VOLUMES**

December 11, 1981

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**JPL Contract 955931
Modification No. 3
Pioneer Work Order 20910**

**This report was prepared for the Jet Propulsion Laboratory
California Institute of Technology, sponsored by the
National Aeronautics and Space Administration.**

TECHNICAL CONTENT STATEMENT

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ABSTRACT

Pioneer Engineering and Manufacturing Company has estimated the manufacturing cost of a General Electric 12 meter diameter concentrator. This parabolic dish concentrator for solar thermal systems was costed in annual production volumes of 100 - 1,000 - 5,000 - 10,000 - 50,000 - 100,000 - 400,000 and 1,000,000 units.

Presented for each volume are the costs of direct labor, material, burden, tooling, capital equipment and buildings. Also presented is the direct labor personnel and factory space requirements.

All costs are based on early 1981 economics.

ACKNOWLEDGEMENTS

Pioneer would like to express its appreciation to those groups and individuals whose cooperation contributed to the completion of this task. The General Electric Space Division personnel were helpful in clarifying elements important to this effort.

Mr. Herbert Fortgang, Technical Manager for JPL, was especially helpful in resolving technical issues.

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SUMMARY

This report presents a manufacturing cost analysis of a parabolic dish concentrator for thermal electric power systems. The specific concentrator is a 12M diameter General Electric design.

This study contains the manufacturing cost for annual production volumes of 100 - 1,000 - 5,000 - 10,000 - 50,000 - 100,000 - 400,000 and 1,000,000 units. Presented for each volume is the cost of labor, material, burden, tooling and equipment. The infrastructure and requirements for direct labor personnel and factory space are also shown. Shipping costs are shown.

All costs are based on early 1981 economics. Costs reflect Detroit area wages and fringes. The processes used for making the parts represent the cost effective techniques dictated by the volume being costed. The reported costs are volume sensitive.

Pioneer's standard methodology was used in deriving the costs. Each part for each volume was processed, time estimated, labor and burden costs computer extended. Burden was applied as an hourly rate for the equipment being used — not as a percentage of labor.

Processes are evaluated so that they are cost effective for the volume. Tooling and equipment costs were estimated to reflect the process used.

"Standard" part costs were obtained from specialty supplier quotations.

INTRODUCTION

1. GE 12M CONCENTRATOR DESIGN

Pioneer Engineering and Manufacturing Company was asked to do a manufacturing cost analysis of a twelve meter parabolic dish concentrator for thermal electric power systems.

The design used in this study was the General Electric 12 Meter Diameter Concentrator. The concept is illustrated in Figure 1. The concentrator is unique in that the support structure is face mounted and the elevation rotation is cradled such as to permit the focal point located receiver to be brought to grade level for servicing. The stow position is with the reflective face down. The pedestal is mounted on a circular track on which the assembly is rotated for azimuth orientation. The system requires a concrete pad forty-four feet in diameter and about two feet thick.

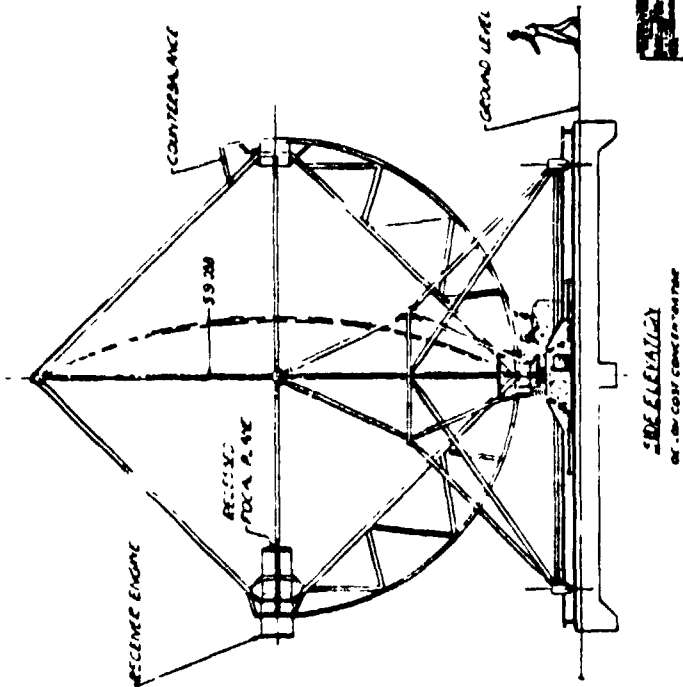
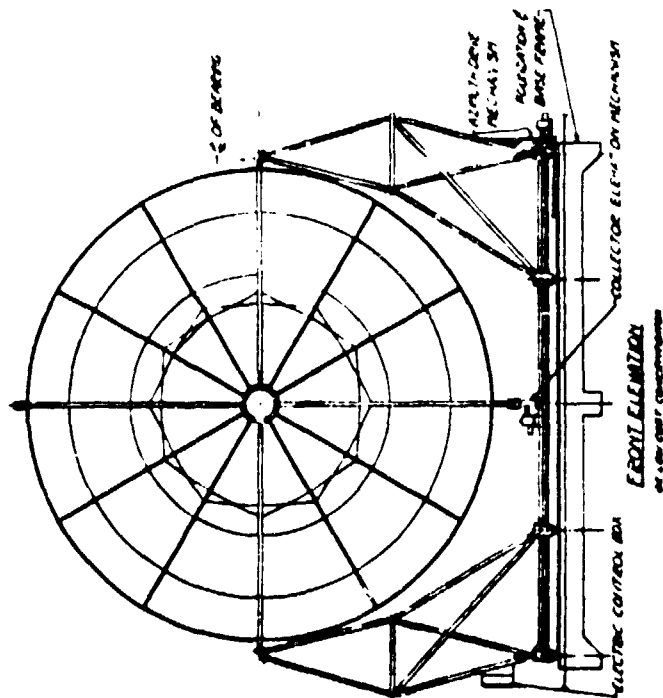
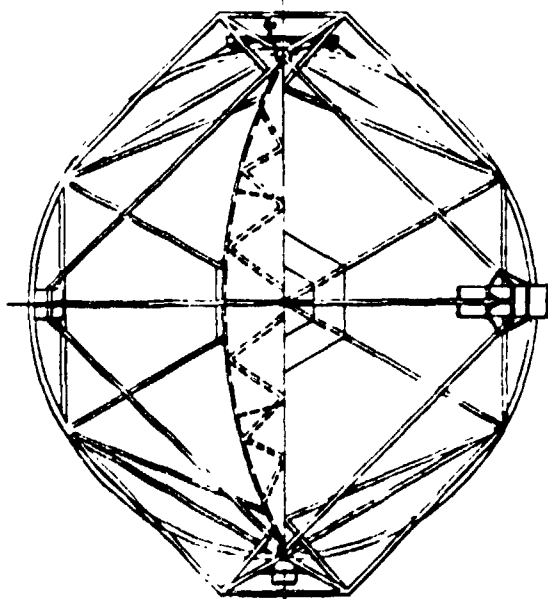
The azimuth and elevation drive motors and speed reducers are mounted at ground level, which improves their maintenance access.

The gore back up structure is plastic laminated balsa wood. (Figure 2) These laminated systems have been used in various commercial applications, most notably as boat hulls. The balsa is end grain mounted on a scrim, slit to one inch by one inch squares having whatever depth is required for the end product. For the gore the blocks are one half inch and one inch deep. The scrim mounted balsa is placed into an encapsulating press where the liquid resin system is forged around it in the required shape to produce the parabolic dish segment. Plexiglass with a reflective tape is bonded to the concave surface and the gore is ready for mounting.

2. COSTING METHODOLOGY

Each part of the assembly was individually costed for each production volume. Eight annual production volumes were considered, 100 - 1,000 - 5,000 - 10,000 - 50,000 - 100,000 - 400,000 and 1,000,000. The production processes selected for each operation of each part in a particular volume represented that process which would produce the part with the lowest investment cost and best utilization. The reported costs are cost effective for the volume considered.

An element in the cost effective choice is the cost of tooling and equipment. These are reported, along with direct labor, material and budget. These cost reflect early 1981 economics, and represent Detroit area wages and fringes.

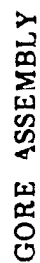


1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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SIDE ELEVATION
OF 1.000 GPM CONCENTRATOR

FIGURE 1.
PARABOLIC DISH CONCENTRATOR

ORIGINAL
OF P. 1000



Burden costs are determined by applying an hourly burden rate to an "occupancy hour" for each operation. Burden is not calculated as a percentage of direct labor. An occupancy hour is the time that a part is in the machine for a given operation. The burden rate is a predetermined hourly cost of operating a given piece of equipment. Its content varies depending on whether it represents a "variable" or a "manufacturing" level cost.

Material costs were obtained by determining part weight and multiplying by the cost per pound of the alloy used in the form required. Form will include plate, sheet, structural shapes. Cost per pound is obtained from the mill or service center, depending on the quantity being used.

The infrastructure requirements and costs are reported. It was assumed that the facility would operate on a two shift basis, producing 4000 man hour per employee per year. The "units per hour" is the net requirement for the volume considered, not the planning volume.

In the design of any production facility there is a point in size after which operating efficiency yields a diminishing return. The size at which that point is reached may be debated but for the sake of illustration here we have chosen the plant capable of building 10,000 units as being optimum. We have tried to show the magnitude of the production volumes by listing the number of 10,000 unit per plant size that would be required for each volume.

In selecting cost effective processes for each volume most of the time they cannot be matched to the required schedule such that they are utilized 100% of the time. This is reflected, to a degree, in the fact that tooling and equipment costs do not increase by the same ratio as the production volume. (Improved processes also contribute to a reduction in unit manpower with volume increases.) Total equipment costs here reflect the use of a given type of machine on any of the 517,000 part numbers required. A type of machine loading has been maintained during costing so that a given type of machine is loaded to 100% capacity before another one is listed as required. Consequently at, say the 1,000,000 unit volume, it was assumed that all the make parts would be produced under the same roof, in order to take advantage of the highest utilization.

It is not practical, however, to build, let alone operate a 52,500 man facility under a roof of 19,530,000 square feet. A more practical alternative is 59 plants of 2,938 employees, each under a roof of 1,128,000 square feet. In the light of the utilization constraints discussed above, none of these 59 plants would be a self-sufficient

entity, producing all its own parts and making complete assemblies. Each plant would specialize in the exclusive production of certain elements, shipping them to a specialized assembly facility. Planning otherwise would lower utilization and add to increased idle capacity and therefore to cost.

A complete set of drawings was provided by JPL for this costing effort. Each major assembly was defined by a complete bill of materials.

Make or Buy decision - The bill of materials was reviewed for a make or buy decision. All so called "standard" parts (catalogue, off-the-shelf items) were classified as "buy" upon the initial review. Vendor quotes were solicited for these items. Subsequently other items were added to the "buy" category based on the cost effectiveness of a "make" or "buy" comparison.

"Make" parts were analyzed for the characteristics that constrained their method of manufacture. As each characteristic was reviewed the equipment necessary to produce that characteristic was defined. Items such as material hardness, part size and shape, tolerance, finish, were all considered in making a good equipment choice. These characteristics, considered in the light of the volume required, determined the number of operations, and the size and type of equipment required.

The general type of part to be considered was defined by the part print. The part print specified whether the part was to be a structural or weldment, a machined bar, a shaped plate or sheet, or whatever other material and shape was required by the design. The design as specified on the drawing was processed for manufacturing; the assumption was made that alternatives were considered by the designer before the choice depicted on the print was made. In effect, the part was costed as designed.

Section 10 of this report does, however, review potential cost reductions related to changes in basic form, such as a weldment replaced by a casting.

Volume effect of process selection - The specific operation selected for producing a part to print is production volume sensitive. That is, the equipment required to perform a given operation will vary as the volume changes. As volume increases, more investment is justified in order to reduce the production time and hence reduce manufacturing cost.

Where high volume machining (and stamping) justified, special machines were conceived and costed. Except in the production of the gore assemblies, the special machines are an application of known technology. Balsa wood laminate structures have

been used in industrial applications for some time. Volume production will require the conception and construction of special molding machinery. The size of a gore section, up to 11' foot long, will require an extension of current technology.

The point at which a given equipment and tooling expenditure is justified is a function of the Return on Investment. ROI calculations for each part at each volume were beyond the capacity of this study. An acceptable approximation of the cost effectiveness of a given process at a given volume is the utilization of the equipment to be used. For this study, a given piece of equipment was considered acceptable if the utilization exceeded 25%. Though this arbitrary utilization is subject to debate, it was considered a viable compromise. This rule was used in applying methods to tools, die fixtures, material handling equipment, as well as machinery.

Inasmuch as the subject collector is essentially a structural weldment, where costs justified automatic (robotics) arc welding techniques were employed. Processing these assemblies for costing required the conception of special fixtures and transfer mechanisms in conjunction with the special features of programmable robots. These concepts were timed and the hardware cost estimated. Vendor quotes were not available for such concepts because of the proposal cost incurred. As a result such costs are estimated by the engineers working on the costing project.

Standard Time Derivation - An essential element in this costing is the application of standard times to an operation. In single station, one machine operations, this time includes unload, load, machine cycle times, and the application of operator allowances.

For multiple station machines, the load and unload times are generally internal to the cycle time of the machine; the cycle time is the time of the slowest operation (or station) plus the index time. The load and unload times are a function of the size, weight, and configuration of the part, as well as the design of the tooling. The estimating engineer must estimate these functions in order to arrive at the cycle time of an operation.

The "allowances" mentioned above account for two types of elements: those associated with the operation per se, and those related to shop operations. Those relating to the specific operation are personal time, tool trouble time, and instruction time. The shop operation allowance covers stock delay time, machine downtime, and off-standard materials.

In considering any metal working operation cost, a decision must be made regarding the number of operators required to perform the operation. This number can vary

from 3 or 4 to as low as 1/10 men per operation. Direct labor costs are a product of the machine cycle per operation multiplied by the hourly rate and that fraction or multiple of a man assigned to the operation.

"Standard" part costs reflect the vendors quoted cost for the quantity being used. The lower material costs for increased quantities result from price breaks for the increased usage.

Shipping Cost - Shipping costs are shown for the two modes that would be available to producers of these concentrators. The choice of mode will be a function of the facilities available. Using a truck will permit loading at the production facility and unloading at the installation site. The truck costs shown assume one unit per truck; with some study it may be possible to package two units to a truck, reducing the trucking cost to almost half the number shown.

The railroad cost reflects a 60,000 pound minimum charge. This concentrator weighs 17,478 pounds. The most economical shipment via rail would be three units per load. This may be accomplished with some ingenuity in packaging. The cost shown are for two units per load, inasmuch as this is more realistic. This would require that the manufacturing facility have a railroad loading dock. For obvious reasons it must be assumed that the railroad cannot unload at the installation site. From the point of railroad unloading, a charge must be made for additional trucking to the installation site. As a rule of thumb, this charge, per for this load, is somewhat higher than the trucking cost shown. For a given load the cost per pound mile increases as the hauling distance decreases.

The shipping costs shown are accurate for this illustration — the choice of mode for the best rate would be determined at the shipping point.

3. DIRECT LABOR COST

Direct labor is the product of direct labor rate, the operation cycle time, and the number of operators assigned to the operation. The determination of cycle time and operator assignment per machine have been discussed previously.

In this cost study the direct labor rate used in labor costs reflects the employers out-of-pocket cost for the employee's services. This includes the gross wages appearing on the employee's check plus all of the fringe benefits earned during employment but not seen directly. These benefits include vacation pay, pension funding, hospitalization, medical, dental and optical costs, sub-pay benefits, uniform allowances, and grievance time.

The labor rates used in the study are Detroit area rates. Labor costs for other areas could be factored per the data in Table 1.

4. BURDEN RATE DERIVATION AND APPLICATION

Burden costs are all the costs of operating a business enterprise over the cost of direct labor and material. Generally, these costs do not include the selling expense, profit, or interest expense on borrowed operating capital. They do include such traditional items as utilities, taxes, insurance, depreciation, all salaries and fringes, as well as the interest expense for money borrowed for the purchase of operating equipment.

There are different approaches to distributing (recovering) burden costs in a manufacturing facility. The simplest approach is to sum the costs over some period of time and determine their relation to the direct labor hours used. That percentage is then applied to the direct labor cost of a product to get the manufacturing cost. This technique is occasionally refined by collection costs by department rather than by plant. Rarely is a major machining center established as a cost center and its operating costs applied to the direct labor hours expended while working on a product.

Using each machine as its own cost center is the most accurate method for distributing cost. This technique is generally avoided because of the expense involved in establishing and maintaining the system. As mentioned above, burden rates are established by the historic accumulation of costs with no regard given to individual machine differences or general efficiency of operations. Poor operating efficiency has a tendency to raise costs, which are recovered from the customer as increased burden. Multi-machine and multi-man operation burden costs are distorted when applied as a function of direct labor.

The burden costs used in this study were developed for each piece of machinery used in a manufacturing process. They are absolute costs per hour of operation — not percentages of other costs. They have been derived using nominal operating costs for a manufacturing facility, operating at nominal efficiencies.

Some of the major factors contained in the burden costs have been discussed above. The complete list contains all of the variable and fixed costs associated with the operation of a given piece of equipment in an average manufacturing environment.

In general, Pioneer method of cost analysis follows the outline shown in Figure 3.

Regional Labor Cost Differences
Source: Industrial Wage Survey
Machinery Mfg.
Jan. 1978 (Published 1979)
Bulletin 2022 - U.S. Dept of Labor
Bureau of Labor Statistics

Chicago - 100
San Francisco - 113
Detroit - 109
Portland (Ore) - 109
Milwaukee - 106
St. Louis - 101
Pittsburgh - 99
Houston - 97
Cleveland - 96
Buffalo - 95
Minn - St. Paul - 93
Philadelphia - 92
Newark - 91
Baltimore - 89
Boston - 88
Hartford - 88
Los Angeles - 87
Worcester - 86
Denver - 85
Tulsa - 84
Dallas - 82
New York - 82
Atlanta - 74

Table 1

ORIGINAL PLAN OF
OF POOR QUALITY

FLOW DIAGRAM
MANUFACTURING COST ANALYSIS
PIONEER METHODOLOGY

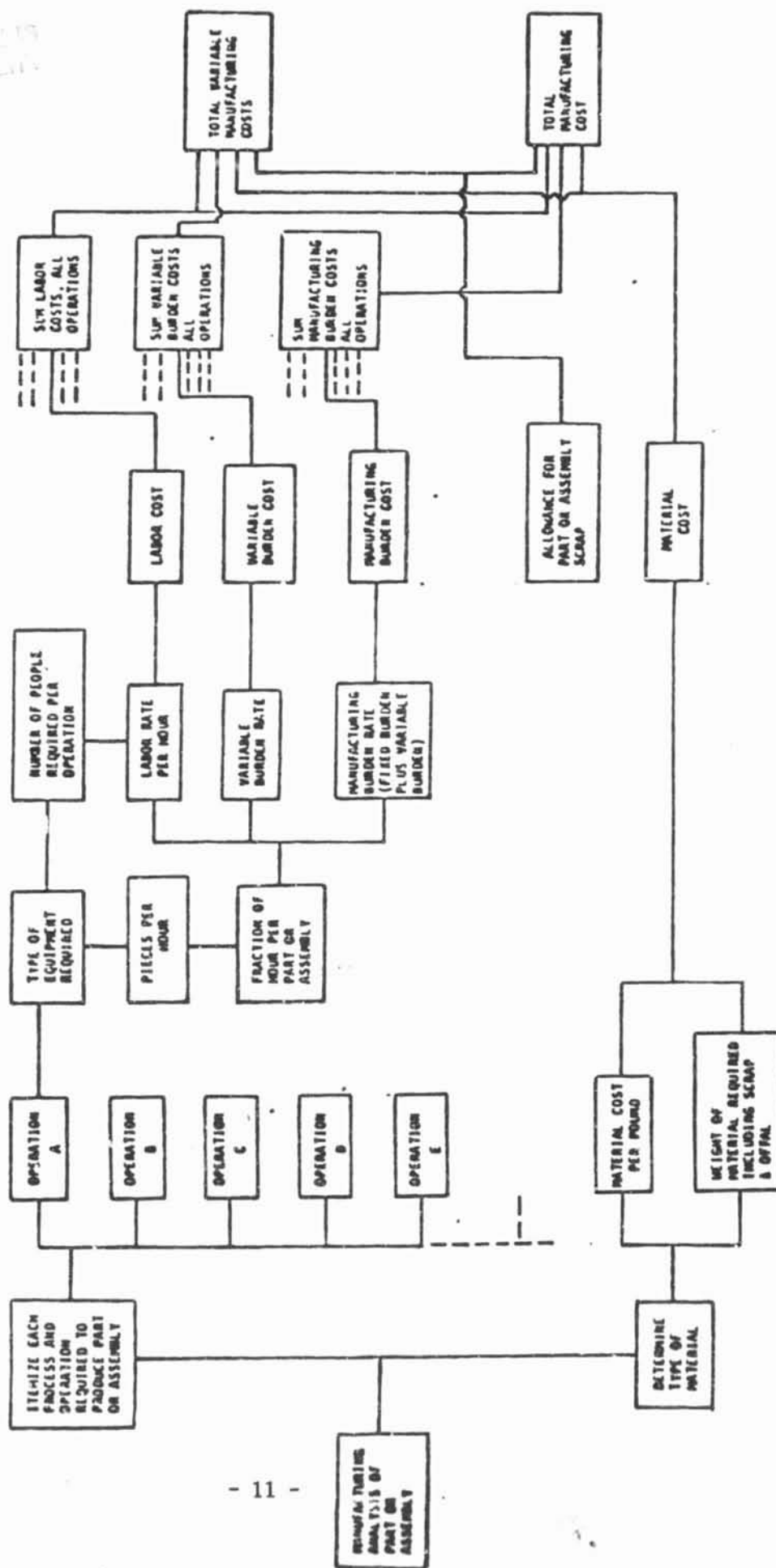


FIGURE 3

5. MATERIAL COSTS

Material costs as submitted in this report consists of --

1. Base material to produce "make" parts
2. Cost of "buy" parts - purchased complete

"Buy" parts consist of electric, electronic, and optical controls, bearings, wire harnesses, motors, wheels, foundation, gear reducers, track, as well as a variety of miscellaneous parts that are more economically produced by speciality houses. The cost of these parts was obtained by soliciting quotations from potential vendors. In some cases quantity purchases caused the price to decline; in many cases the cost was constant.

"Make" parts, in this case, are primarily weldments comprised of standard structural plate and sections. The cost of these structural sections was obtained from verbal quotations from a mill at mill lot orders. Even at the low end of the annual volumes (1,000 units) the steel requirements permitted mill lot pricing for some.

It may be of some passing interest to note that this concentrator used 840 board feet of balsa wood. The world production of balsa wood averages 30 million board feet. This would be sufficient to produce close to 36,000 twelve meter concentrators. Balsa wood suppliers indicate that the supply, however, with minimal management effort, could be expanded to meet the requirements of a 1,000,000 unit annual production.

COST REDUCTION REVIEW

GENERAL

Cost reduction improvements of any product must address themselves to the function of the characteristic being changed. A change in function is frequently accompanied by a change in basic design. In stress sensitive designs this must be followed by some degree of analysis and calculation. Where these kinds of functional changes cannot be made because stress analysis cannot be done, changes for cost reduction must be limited to a change in form, i.e. weldment to casting, solid bar to weldment, etc.

Cost reduction is best done in the design phase. Too often design concepts represent functional but not production oriented hardware. As a result the released design suffers from high cost and inertia to change.

The changes suggested here represent the do's and don'ts of manufacturing engineering technology, which result in manufacturing feasibility at minimum cost of labor, material and equipment to produce the function. The parts discussed here are only a sample of the total savings that might result from a complete production engineering review with a stress verification.

1. FITTING - OUTER END - P.N. 47E258006 - Figure 4

This part calls for AISI 1018 steel. This spec requires that it be made from 3½ plate. This makes it necessary to machine away 47 pounds of material, at a purchase cost of \$12.22. The cost to burn and machine away that material is \$2.28 (at 100,000 units). If made as a weldment (Figure 5) the cost would be reduced by 53% to \$11.97.

This is a representative sample of similar changes in form on other parts that would reduce cost by the same ratio.

2. TRUNNION FITTING - P.N. 47E258024 - Figure 6

Material spec is AISI 1018. 10.44 pounds of material must be removed at a cost of \$5.00 in labor, material, and burden. Making the "H" section (Figure 7) as a weldment would save \$3.75, for a 13% reduction in cost.

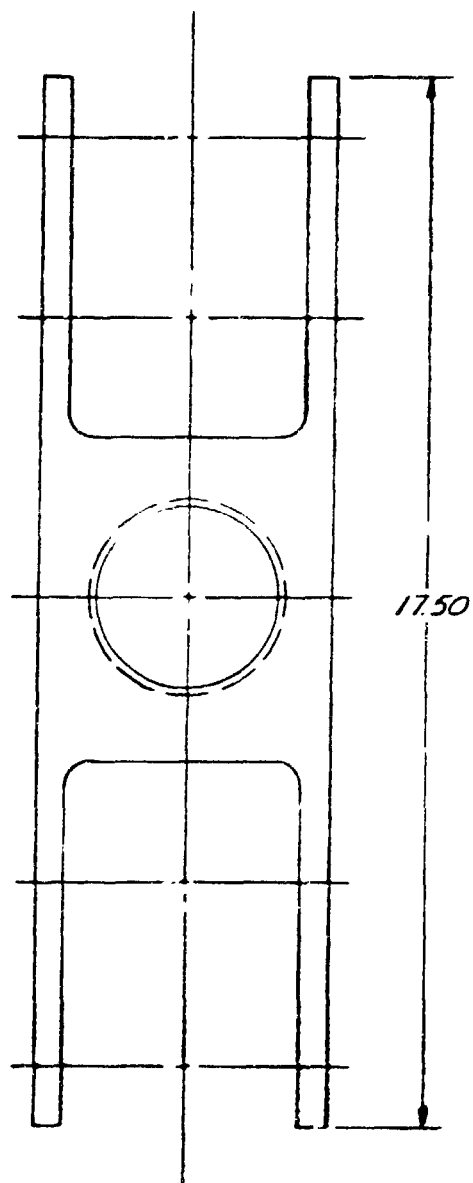


FIGURE 4
FITTING - OUTER END

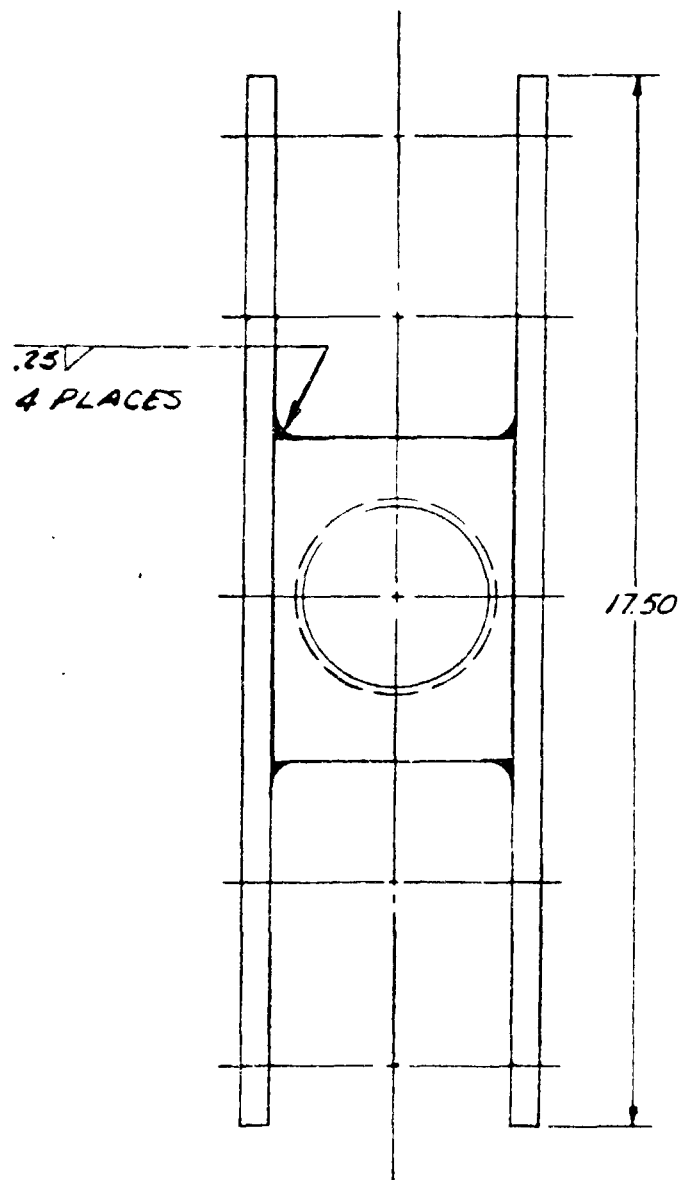


FIGURE 5
FITTING - OUTER END REVISED

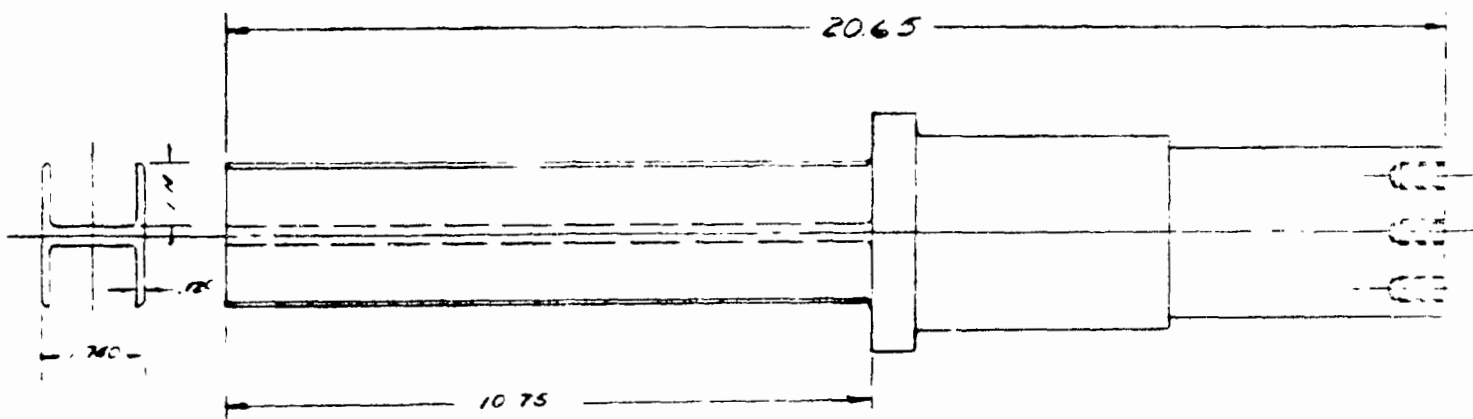


FIGURE 6
TRUNNION FITTING

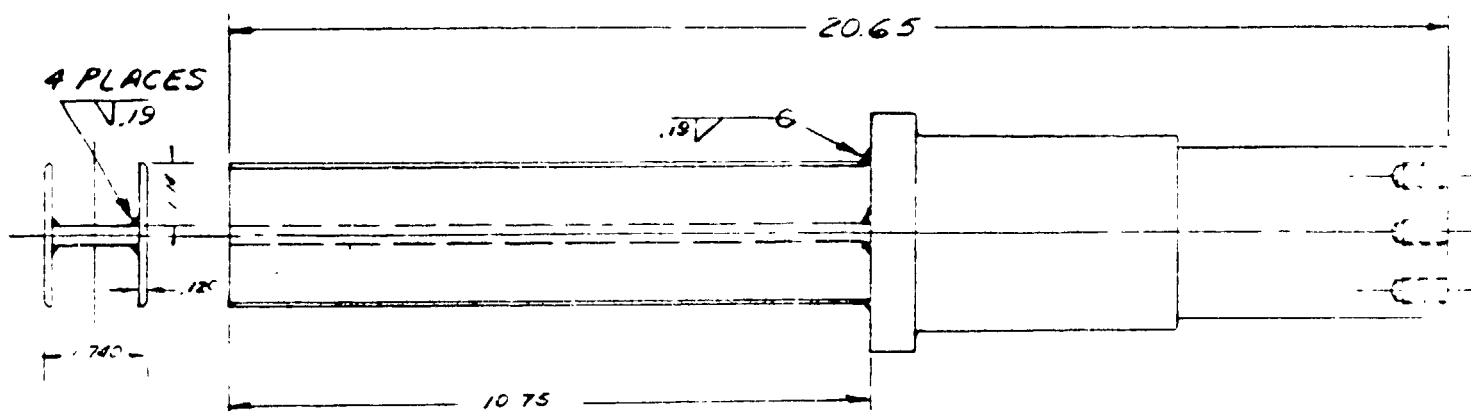


FIGURE 7
TRUNNION FITTING REVISED

3. GUSSET - TRUNNION FITTING - P.N. 47D258015 - Figure 8

Material spec is AISI 1018. Made from plate, 40% of the material is machined away, representing 34% of the total cost of the part. Designed as a weldment, (Figure 9) the material cost, which is 86% of the part cost, would be further reduced. This form would be economical, however, only in the smaller volumes, 50,000 and less. In the higher volumes a casting would substantially reduce the material cost.

In quantities of 100,000 and above the machining time is a minor cost item because of an equipment investment of \$1,200,000 to permit dial mach drill of the holes and C'Bores.

4. STRUT FITTING - P.N. 47E258023 - Figure 10

Material spec is AISI 1018. This four piece weldment, if made as a casting would result in an 11% savings at the 100,000 unit level. The savings result from material reduction, i.e., offal is reduced. Further savings at higher volumes may result in automated machining of the holes. At low volumes, 1,000 units (4,000 fittings) the weldment remains the best choice.

5. STRUT FITTING - P.N. 47E258072-P1 - Figure 11

Material spec is RCQ-100. This part is included here merely to illustrate the savings that can result from a simple change in dimensioning philosophy. The illustrated part would be made from standard bar stock to achieve the lowest material cost. Standard bars are produced in one inch increments. It is not an efficient use of time and material to require a decimal dimension for a characteristic that merely hangs in space. In the example shown, if the 8.32 dimension is required for stress, it should have been made 8.5; or if .160 stock could be removed without jeopardizing stress, the dimension could easily be .000. Either case would reduce cost, the latter being preferred. The same logic may be applied to the 4.10 dimension.

The slight angle, "A", appears to be there simply for the sake of symmetry. Its removal would reduce cost and not interfere with function.

6. PULLEY TENSIONER - P.N. 47E258043 - Figure 12

Material spec is AISI 1018, 1045. Here is an example of a weldment that looks as though it may be made more economically as a casting. (Figure 13) Without a change in material cost per pound, eliminating the assembly and welding results in a

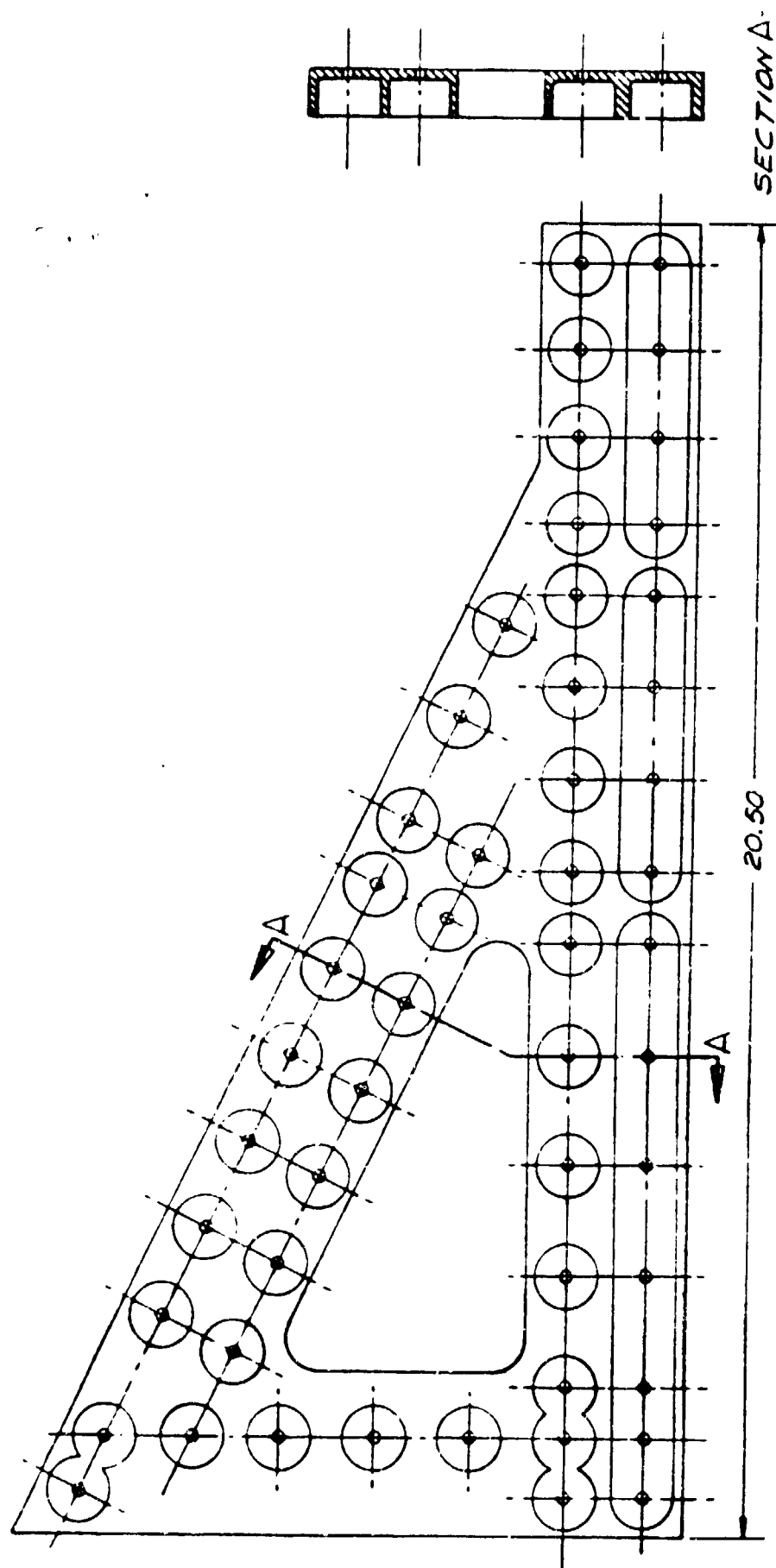
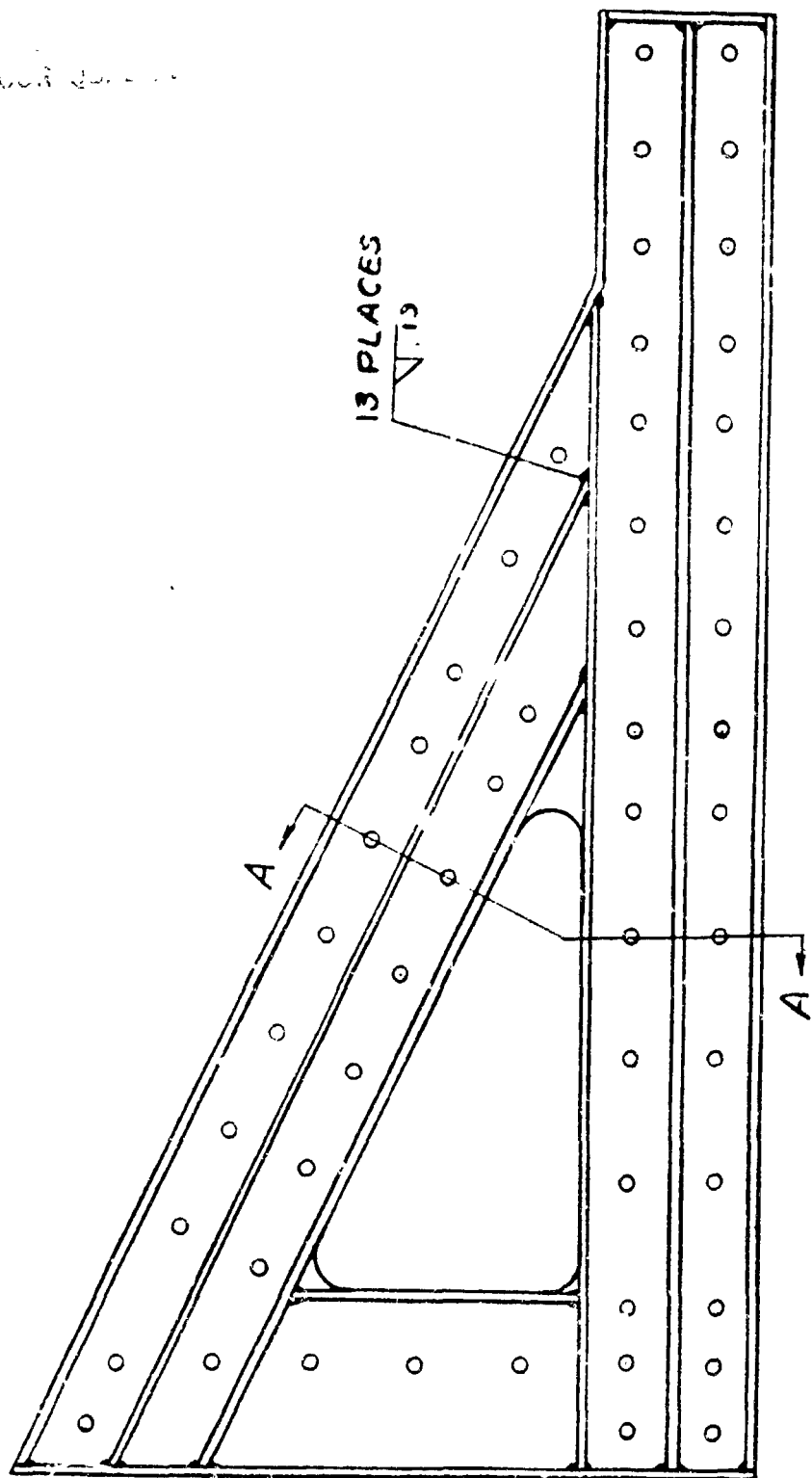


FIGURE 8
GUSSETT - TRUNNION FITTING

OF FLOOR JOIST

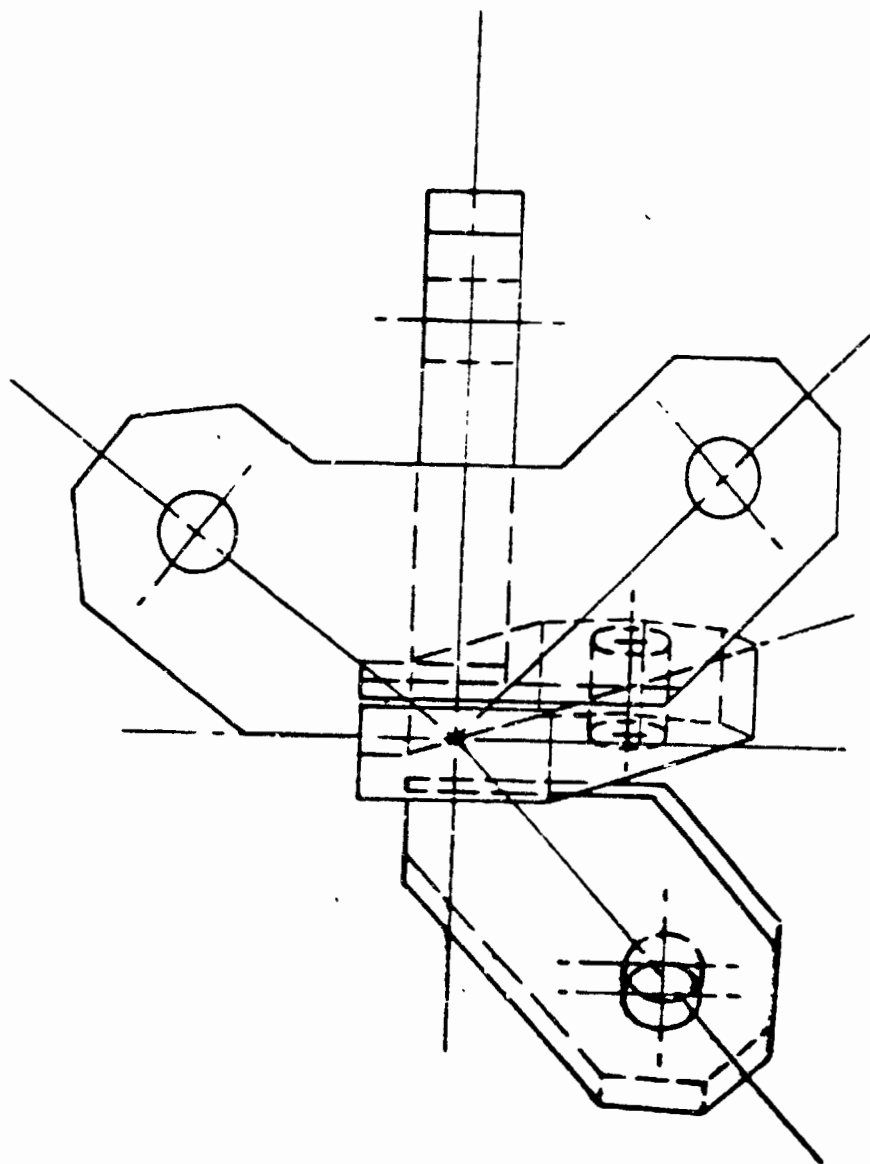


SECTION A-A

PROPOSED DESIGN

FIGURE 9

GUSSET - TRUNNION FITTING REVISED



CENT
OF FOCUS

FIGURE 10
STRUT FITTING

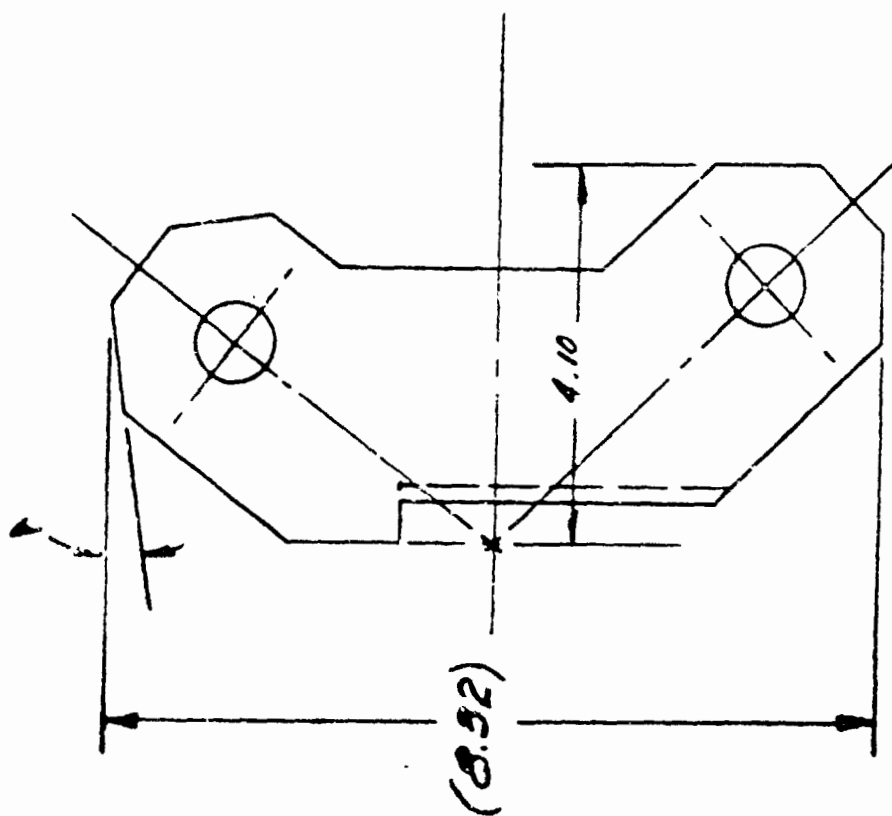


FIGURE 11
STRUT FITTING REVISED

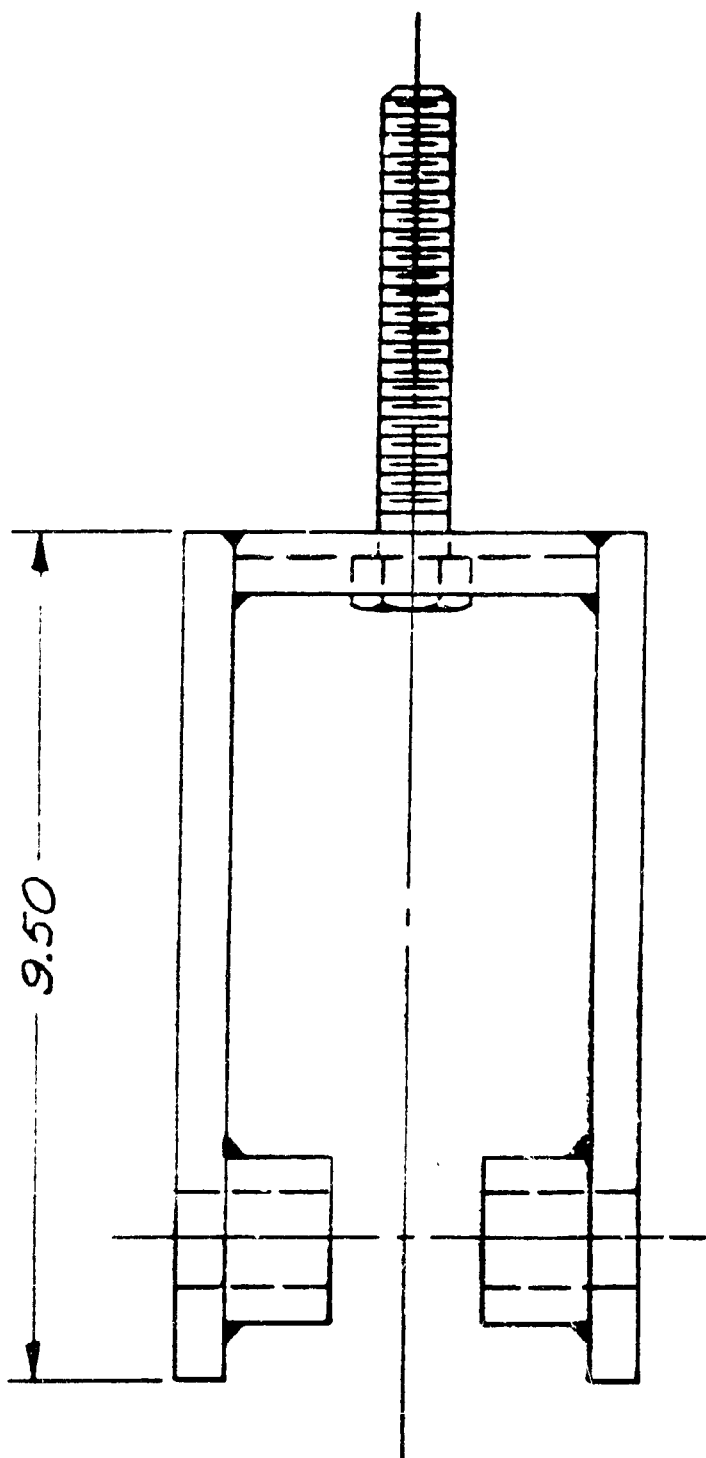


FIGURE 12
PULLEY TENSIONER

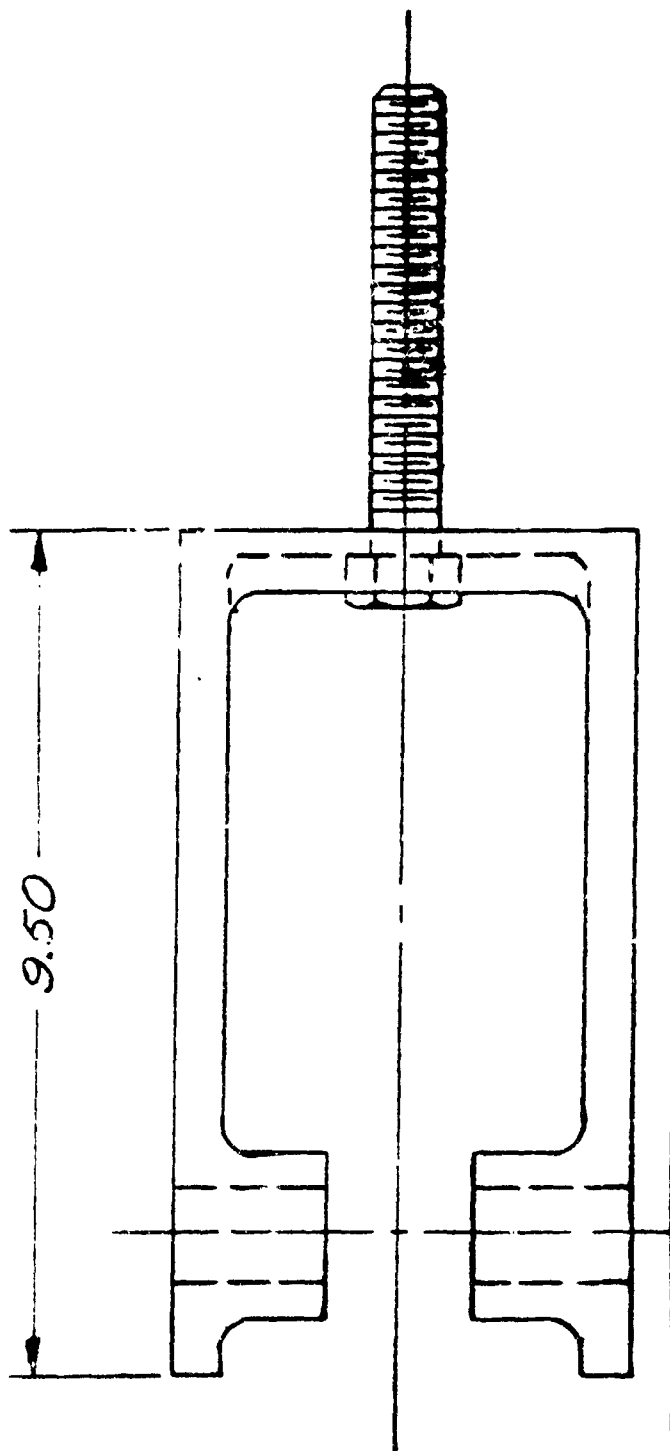


FIGURE 13
PULLEY TENSIONER REVISED

saving of 70%. However, the casting cost per pound is increased such that using a casting is a price trade off. Without a change in the design the advantage to a casting would be the decrease in flat stock inventory and reduced production control what with having fewer parts to schedule.

A change in the design, such as making the 3.00 inch wide side increased into 2.60 inches, would save .71 per assembly with a casting. This would apply to volumes 10,000 a year and over.

At lower volumes the weldment is the best design, inasmuch as tooling and equipment costs cannot be justified for a casting.

RESULTS

This study developed Manufacturing (Material + Labor + Burden) cost numbers for the GE designed 12 Meter diameter parabolic dish concentrator in annual production quantities of 100 - 1,000 - 5,000 - 10,000 - 50,000 - 100,000 - 400,000 and 1,000,000 units. All costs are expressed in early 1981 economics.

Table 2 presents the complete manufacturing costs of the concentrator for the annual production quantities evaluated. The cost of capital equipment is included in the manufacturing burden - however, the cost of tooling is not.

Table 3 shows the production infrastructure required.

The cost (labor, material, burden) of the concentrator varies from a low of \$15,981 to a high of \$25,403, depending on the annual production volume.

Tooling costs range from a high of \$172,268,000 to a low of \$694,000.

Machinery and equipment costs vary from a high of \$2,201,382,000 to a low of \$5,722,000.

The direct labor personnel required varies from a low of 18 to a high of 52,000 depending on the annual production volume.

Table 4 presents the cost of shipping the concentrator from a factory to the assembly site using either truck or rail facilities.

SUMMARY
MANUFACTURING COST
PARABOLIC DISH CONCENTRATOR
(GE 12M DIAMETER DESIGN)

ANNUAL PRODUCTION VOLUME	WEIGHT/ ASSY.	MATERIAL \$	LABOR MIN.	LABOR \$	BURDEN \$	TOTAL COST	COST \$/M ²	TOOLING -000-	EQUIPMENT -000-
100	17,478	21,764	11,250	2,233	1,486	25,483	226	694	5,722
1,000	17,478	20,882	10,409	2,029	2,184	25,095	222	1,320	8,770
5,000	17,478	14,226	10,603	2,096	2,307	18,629	165	3,445	23,706
10,000	17,478	14,158	7,948	1,607	1,679	17,444	154	5,850	37,440
50,000	17,478	14,015	5,632	1,177	1,251	16,443	146	17,465	140,032
100,000	17,478	13,983	5,233	1,153	1,164	16,300	144	27,234	279,016
400,000	17,478	13,850	5,065	1,072	1,126	16,048	142	73,840	960,981
1,000,000	17,478	13,804	5,040	1,062	1,115	15,981	141	172,268	2,201,382

Table 2

SUMMARY
PRODUCTION INFRASTRUCTURE
PARABOLIC DISH CONCENTRATOR
(GE 12M DIAMETER DESIGN)

ANNUAL PRODUCTION VOLUME	HRS/UNIT	DIRECT LABOR PERSONNEL*	UNITS/HR	PLANT AREA -000- SQ. FT.	BLDG. COST -000- \$	NO. OF PLANTS 10M SIZE
100	188	18	.025	15	1,200	.05
1,000	173	108	.25	43	3,406	.14
5,000	177	553	1.25	217	17,013	.68
10,000	132	825	2.5	320	24,840	1
50,000	94	2,938	12.5	1,128	86,630	3.5
100,000	87	5,438	25	2,066	157,016	6.3
400,000	84	21,000	100	7,896	593,779	24
1,000,000	84	52,500	250	19,530	1,453,032	58.5

*Assume two shifts

Table 3

SUMMARY
SHIPPING COSTS
PARABOLIC DISH CONCENTRATOR
(GE 12M DIAMETER DESIGN)

SHIPPING	-	TRUCK	-	\$	395	Per Unit	-	300 Mile Radius
					704	Per Unit	-	800 Mile Radius
		*RAIL	-	\$	286	Per Unit	-	300 Mile Radius
					526	Per Unit	-	800 Mile Radius
							-	3 Per Flatcar
							-	3 Per Flatcar

*Add hauling costs from unloading site to installation site to RR shipping costs.

Table 4